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WHY THE "PLUMBBOB GAMMA DECAY" (PGD) CURVE IS AN INCORRECT MODEL FOR EXTERNAL GAMMA-EXPOSURE RATE AS A FUNCTION OF TIME: A COMMENT ON "CONTINENTAL CLOSE-IN FALLOUT: ITS HISTORY, MEASUREMENT, AND CHARACTERISTICS"

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ABSTRACT

During atmospheric testing of nuclear devices in the 1950s, the primary measurement upon which external gamma exposure could be calculated was the external exposure rate. Integration of the external exposure rate requires a model of how the rate decreases with time. Typically the approximation was used that exposure rate decreased as the negative 1.2 power of time, and later additional factors were added to describe weathering. However, for the Plumbbob series a different model was used and was based upon laboratory measurements of the gamma-emission rate of small samples of fallout. This model is described in the preceding paper and became known as the "Plumbbob gamma decay" (PGD) curve. The use of this PGD model leads to integrated exposures higher by factors of 1.5 to 2.0 compared to those calculated with the previously used model. In this paper, data on external gamma-exposure rate measured in the field following the Smoky event of the Plumbbob series are compared to both models. The author concludes that the "Plumbbob gamma decay" curve does not fit the actual data, and that the traditional $t^{-1.2}$ approximation, modified for weathering, is a better representation of the data.

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INTRODUCTION

In the preceding paper, Larson (1983) has described many aspects of the early studies of close-in continental fallout conducted by UCLA. Among the studies described were those conducted during Operation Plumbbob to establish the rate of radioactive decay of fallout debris (pp. 16-18 and pp. 36-37 in Larson, 1983). It is stated that

> ...Beta decay curves of most detonations approximated the $T^{-1.2}$ decay relationship over a period of H + 12 to H + 6000 hours...
>
> Decay curves of the gamma emission rate were different from those of beta decay for fallout debris from a specific detonation...
>
> Estimates of dosage in fallout areas have generally been based, in part, on a decline of dose rate (mr/hr) with time according to the $T^{-1.2}$ relationship. A dose rate decline with time according to the Plumbbob gamma decay (PGD) curve yields calculated doses which are 1.5 to 2 times greater than those calculated by the $T^{-1.2}$ relationship for different fallout times to approximately 400 days after detonation (Table 7).

The above quotations are based upon measurements of the <u>gamma-emission</u> rate of fallout samples that were collected and returned to the laboratory for subsequent measurement. Clearly, the rate of <u>gamma emission</u> as measured in the laboratory on a small sample is not necessarily a valid indication of the rate of external <u>gamma exposure</u> as experienced in the field. This is because 1) there is no assurance that the measured rate of gamma emission was corrected for detector efficiency as a function of energy and 2) the rate of gamma exposure depends upon both the energy of the emitted gammas and the mass absorption coefficient of air as a function of energy.

Because the "Plumbbob gamma decay" (PGD) curve as described by Larson was used to calculate radiation "doses" (really exposure in modern terminology) for the Plumbbob series, I wish to examine the validity of this concept in this paper. This matter is of current concern because several of the principals and managers of the NAEG are also presently involved in reconstructing the radiation doses (external and internal) received by off-site residents from these historic tests of nuclear explosives. Thus, while Larson's account may be accurate in reporting the measurements made, some of the conclusions drawn from the data are not necessarily valid or supported by data taken by other investigators. Because of the appearance of Larson's paper in a NAEG publication, it might be implied that the NAEG and its investigators endorse everything stated in his paper. This is not the case and I believe the "Plumbbob gamma decay" (PGD) curve is an inaccurate concept that has lead to an overestimate of external gamma exposures from Operation Plumbbob.

During the 1950s, the Test Manager for the Atomic Energy Commission's Nevada Test Site appointed a committee to determine external gamma exposures to people in local communities. Their charter encompassed all events from the Ranger series in 1951 through the Hardtack II series in 1958. This group was known as the Test Manager's Committee to Establish Fallout Doses (TMCEFD) or as the Vay Shelton Committee after its Chairman. The TMCEFD results for cumulative exposures were released in 1959 (Shelton *et al.*, 1959). It was this Committee that chose to use the "Plumbbob gamma decay" (PGD) curve to calculate external gamma exposures for Operation Plumbbob, although they used different techniques for earlier and later series.

METHODS USED BY THE TMCEFD TO CALCULATE EXTERNAL GAMMA EXPOSURES

Measurements to document external gamma exposure from fallout fields were commonly made with exposure-rate instruments. Because measured external gamma-exposure rates decreased rapidly with time following detonation and because it was desired to construct isopleths of exposure, it was necessary to have some relationship to describe external gamma-exposure rate as a function of time following detonation. Otherwise, all the measurements that were necessarily made at many different times following detonation could not be normalized to a common basis.

The convention was frequently adopted that the external gamma-exposure rate, $R(t)$, at a given location varied with time, t, according to

$$R(t) = R(1)t^{-1.2} \qquad (1)$$

where $R(1)$ is the exposure rate at $t = 1$ h. This became known as the $t^{-1.2}$ "law" and was apparently based upon theoretical calculations by Way and Wigner (1948), as well as experimental measurements over tens of hours following the detonation.

Because external gamma exposure to people depended upon the integral of external gamma-exposure rate over long time periods, Dunning (1957a,b) measured the decreasing external gamma-exposure rate over periods as long as two years and concluded that a reasonable relationship was

$$R(t) = \begin{cases} R(1)t^{-1.2} & \text{for} \quad t < 168\ \text{h} \\ bR(1)t^{-1.3} & \text{for} \quad 168\ \text{h} < t < 336\ \text{h} \\ cR(1)t^{-1.4} & \text{for} \quad 336\ \text{h} < t \end{cases} \tag{2}$$

where b and c are constants required for continuity.

External exposure to people can be calculated by integration of R(t) with proper allowance for shielding by buildings. A crude estimate of external gamma exposure, with no allowance for shielding, can be obtained by integrating Equation (1) from time of arrival, a, to infinite time:

$$IE = R(1) \int_a^{\infty} t^{-1.2} = 5R(1)a^{-0.2} . \tag{3}$$

Results of calculations with the use of Equation (3) were referred to as infinite exposure (IE).

A more realistic estimate of exposure to people is made by integrating Equation (2) from time of arrival to one year (8760 h):

$$EE = 0.75\ R(1) \left[\frac{1}{0.2} (a^{-0.2} - 168^{-0.2}) + \frac{168^{0.1}}{0.3} (168^{-0.3} - 336^{-0.3}) + \frac{2^{0.1} \cdot 168^{0.2}}{0.4} (336^{-0.4} - 8760^{-0.4}) \right] \tag{4}$$

where 0.75 is a shielding factor (Dunning 1957a). The results of such calculations were referred to as estimated exposure (EE).

The TMCEFD used Equation (4) to estimate fallout exposures for all test series through 1955. For the 1957 Plumbbob series, they used the "Plumbbob gamma decay" (PGD) curve described by Larson (1983). For the 1958 Hardtack II series, they used the markedly different approach of using exposure measured by film badges (Anspaugh and Church, 1984, provide a more detailed explanation of these procedures).

IS THE "PGD CURVE" A VALID MODEL FOR EXTERNAL EXPOSURE RATE?

Of primary interest here is whether the PGD curve as described by Larson (1983) is the best representation of the decay of the external gamma-exposure rate for Plumbbob events. In order to examine this issue, I will illustrate with data from event Smoky, which caused the largest exposure to people of any event in the Plumbbob series (Anspaugh and Church, 1984).

Fortunately, there was a large body of data taken to study the rate of decay of the Smoky external gamma-exposure field; measurements were made both by the Public Health Service and by the Army. All of these data have been tabulated and published recently by Quinn et al. (1982). Their plots of these data are reproduced here as Figs. 1-3. The line in these figures labeled "$t^{-1.26}$ DECAY RATE" is their best estimate of a fit of a single power function to the data.

Of more interest here is how these data compare to the "Plumbbob gamma decay" (PGD) curve described by Larson (1983). Such a comparison is shown in Fig. 4 where the Army data are compared with the PGD curve and the curve plotted from Equation (2). (Values for the PGD curve were taken from Table A-2 or extracted from Fig. 1 of Larson (1983). Both curves were constrained to match the data at 360 mR/h at 4 hours post detonation.)

As can be seen from Fig. 4, the PGD curve departs from the actual data after 10 hours post detonation and overestimates the measured external gamma-exposure rate by a factor of 2 by 100 hours post detonation. The curve plotted from Equation (2) also overestimates the measured data at late times, but is a much more accurate match to the data. The data plotted in Fig. 4 were measured with two different instruments. At external gamma-exposure rates >10 mR/h, the T1B was used; at <10 mR/h, the Beckman MX-5 was used. Larson (1983) in his Table A-1 suggests that data taken with an MX-5 should be multiplied by 1.3 to make them comparable to data taken with a T1B. Quinn et al. (1982) found that the Smoky monitoring data did not support this old rule of thumb. However, if the measured data points <10 mR/h shown in Fig. 4 were multiplied by 1.3, they would nearly match the values predicted by Equation (2).

Obviously, a time series of measurements made in the field with an external gamma-exposure-rate meter is a much more accurate representation of the external gamma-exposure rate as a function of time than is the measurement of the gamma-emission rate of a small laboratory sample. As Fig. 4 clearly indicates that the two measurements are not equivalent, I conclude that the "Plumbbob gamma decay" curve is not a valid model for the external gamma-exposure rate as a function of time.

A reasonable question is whether Smoky was an atypical event of the Plumbbob series. Several other events were also measured in a similar manner by the Public Health Service, but the results have not been reported in detail. Gilmore (1958) did analyze such data in terms of fitting a single power function to them; the results are similar to those for Smoky.

IMPACT OF USING THE "PGD CURVE" TO CALCULATE EXPOSURE

Figure 5 is taken from Shelton et al. (1959) and compares integrated external gamma exposures calculated by using the "Plumbbob gamma decay" curve versus those calculated by integrating Equation (1) for various time periods. As stated by Larson (1983), the exposures calculated by integrating the "PGD" curve are about 1.5 to 2.0 times higher than those calculated by integrating $t^{-1.2}$.

Also, since neither of the above constructs allows for weathering, there is some additional overprediction of the external gamma exposure by either equation as compared to that predicted by Equation (4). The net result is that the external gamma exposures calculated and reported for the Plumbbob series are too high by a factor of about two.

CONCLUSION

External gamma exposures calculated by the TMCEFD for the Plumbbob series using the "Plumbbob gamma decay" curve are too high by a factor of about two. This conclusion is based upon an examination of external gamma-exposure-rate data actually measured in the field during the Plumbbob series. Such data are consistent with the traditional model of external gamma-exposure rate as a function of time and are inconsistent with the "Plumbbob gamma decay" curve.

REFERENCES

1. Anspaugh, L.R. and B.W. Church. 1984. "Historical Estimates of External Gamma Exposure and Population External Gamma Exposure from Testing at the Nevada Test Site. I. Test Series through Hardtack II, 1958." Health Physics (submitted).

2. Dunning, G.M. 1957a. "Radiations from Fallout and Their Effects," in The Nature of Radioactive Fallout and Its Effects on Man, Hearings Before the Joint Committee on Atomic Energy, Congress of the US, Washington, DC, Part 1, pp. 170-196.

3. Dunning, G.M., Ed. 1957b. Radioactive Contamination of Certain Areas in the Pacific Ocean from Nuclear Tests, US Atomic Energy Commission, Washington, DC.

4. Gilmore, R.A. 1958. "Weathering Studies," Public Health Service, Las Vegas, NV, unpublished report (available from the Coordination and Information Center, REECo, P.O. Box 14400, Las Vegas, NV).

5. Larson, K.H. 1983. "Continental Close-In Fallout. Its History, Measurement, and Characteristics." This volume.

6. Quinn, V.E., N.C. Kennedy, and V.D. Urban. 1982. "Analysis of Operation Plumbbob Nuclear Test Smoky Radiological and Meteorological Data," Weather Service Nuclear Support Office, NOAA, Las Vegas, NV, NVO-249.

7. Shelton, A.V., R.H. Goeke, W.R. Kennedy, K.H. Larson, K.M. Nagler, and O.R. Placak. 1959. "Exposures Prior to 1960. Report of the Test Manager's Committee to Establish Fallout Doses to Communities Near the Nevada Test Site," unpublished report (available from the Coordination and Information Center, REECo, P.O. Box 14400, Las Vegas, NV).

8. Way, K. and E.P. Wigner. 1948. "The Rate of Decay of Fission Products," Phys. Rev. 73, 1318-1330.

FIGURE CAPTIONS

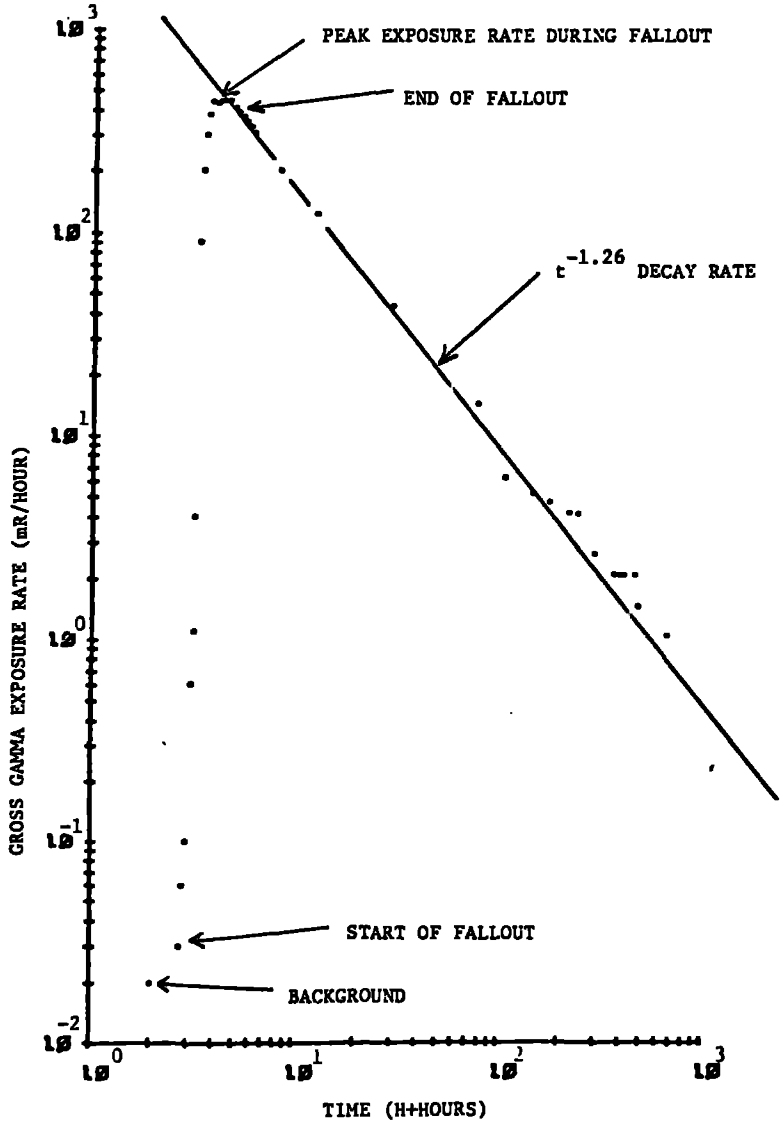
Figure 1. External gamma-exposure rate versus time as measured by the Public Health Service on U.S. Highway 93 at Kane Springs Wash, Nevada, following event Smoky of the Plumbbob series. This Figure is reproduced from Quinn *et al*. (1982).

Figure 2. External gamma-exposure rate versus time as measured by the Public Health Service at Butler Ranch, Nevada, following event Smoky of the Plumbbob series. This Figure is reproduced from Quinn *et al*. (1982).

Figure 3. External gamma-exposure rate versus time as measured by the U.S. Army 5 miles north of Kane Springs Wash, Nevada, following event Smoky of the Plumbbob series. This Figure is reproduced from Quinn *et al*. (1982).

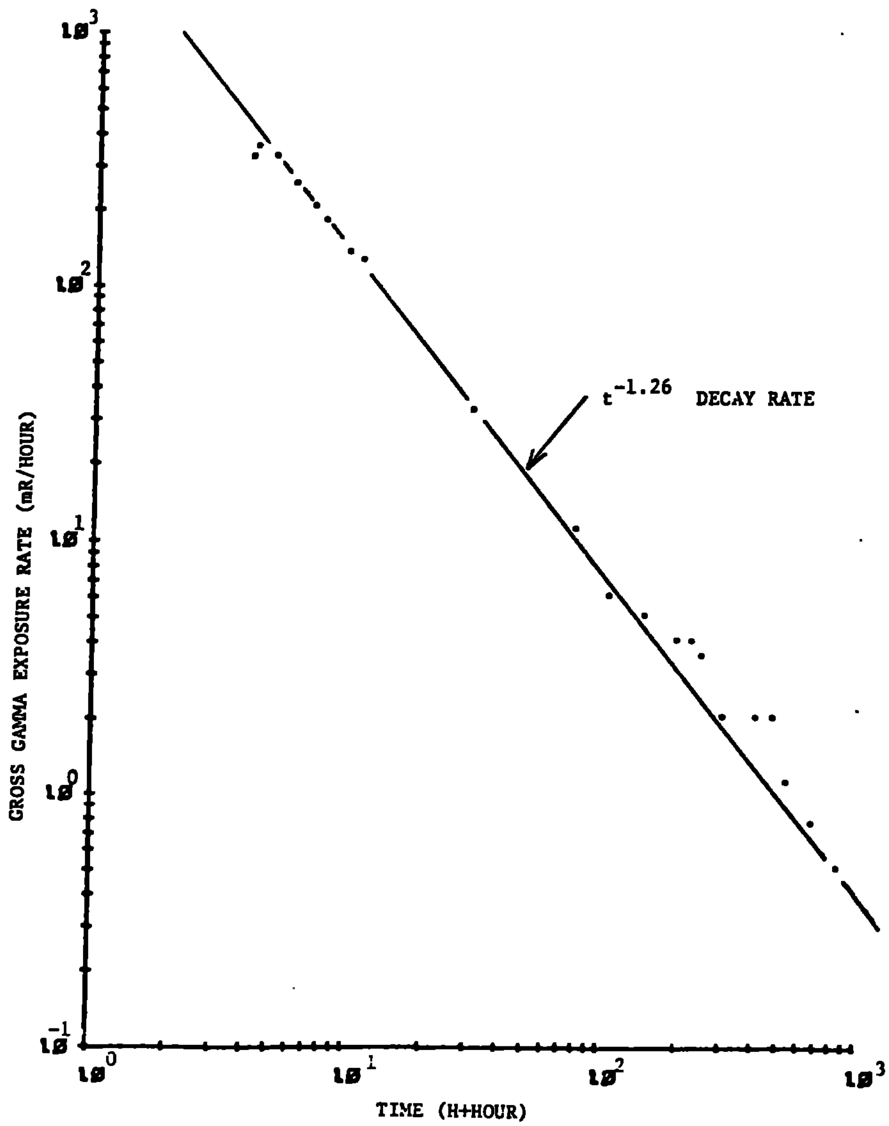
Figure 4. A comparison of the measured external gamma-exposure rate versus time for event Smoky with that of two predictive models: the "Plumbbob gamma decay" curve and the curve described by Eq. (2) in the text. The points represent measurements by the U.S. Army and were taken from the tabulation by Quinn *et al*. (1982).

Figure 5. A comparison of external gamma exposures calculated by integration of two models of the decrease of exposure rate with time. The upper curve represents integration of the "Plumbbob gamma decay" curve extended by the $t^{-1.2}$ relationship for times longer than those for which measurements were made. The lower curve represents integration of $t^{-1.2}$. Each integration is done with the assumption of cloud arrival at H + 6 h with an initial external gamma-exposure rate of 100 mR/h. This Figure has been redrawn from the graph in Shelton *et al*. (1959). The word "dose" appears in the original, but should read "exposure" as we use the words today.



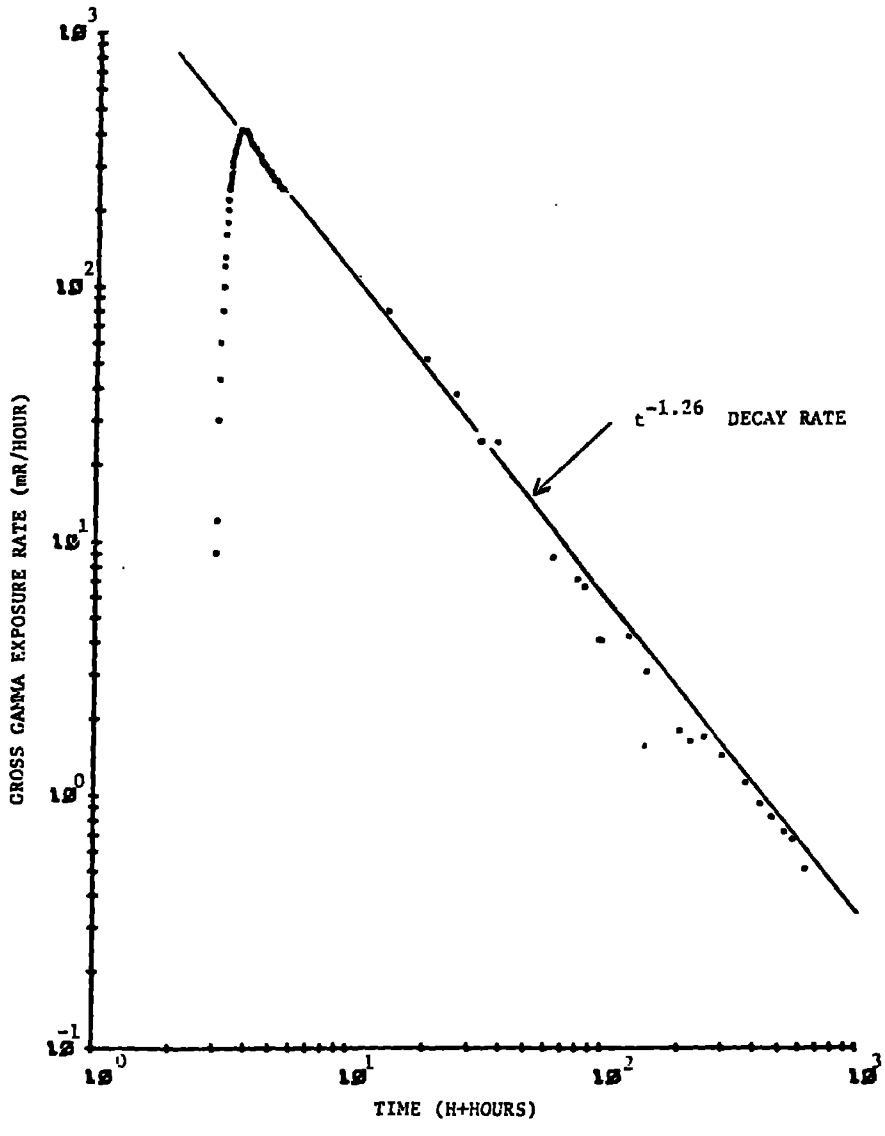
PEAK EXPOSURE RATE DURING FALLOUT
END OF FALLOUT
t^-1.26 DECAY RATE
START OF FALLOUT
BACKGROUND
GROSS GAMMA EXPOSURE RATE (mR/HOUR)
TIME (H+HOURS)

Figure 1.



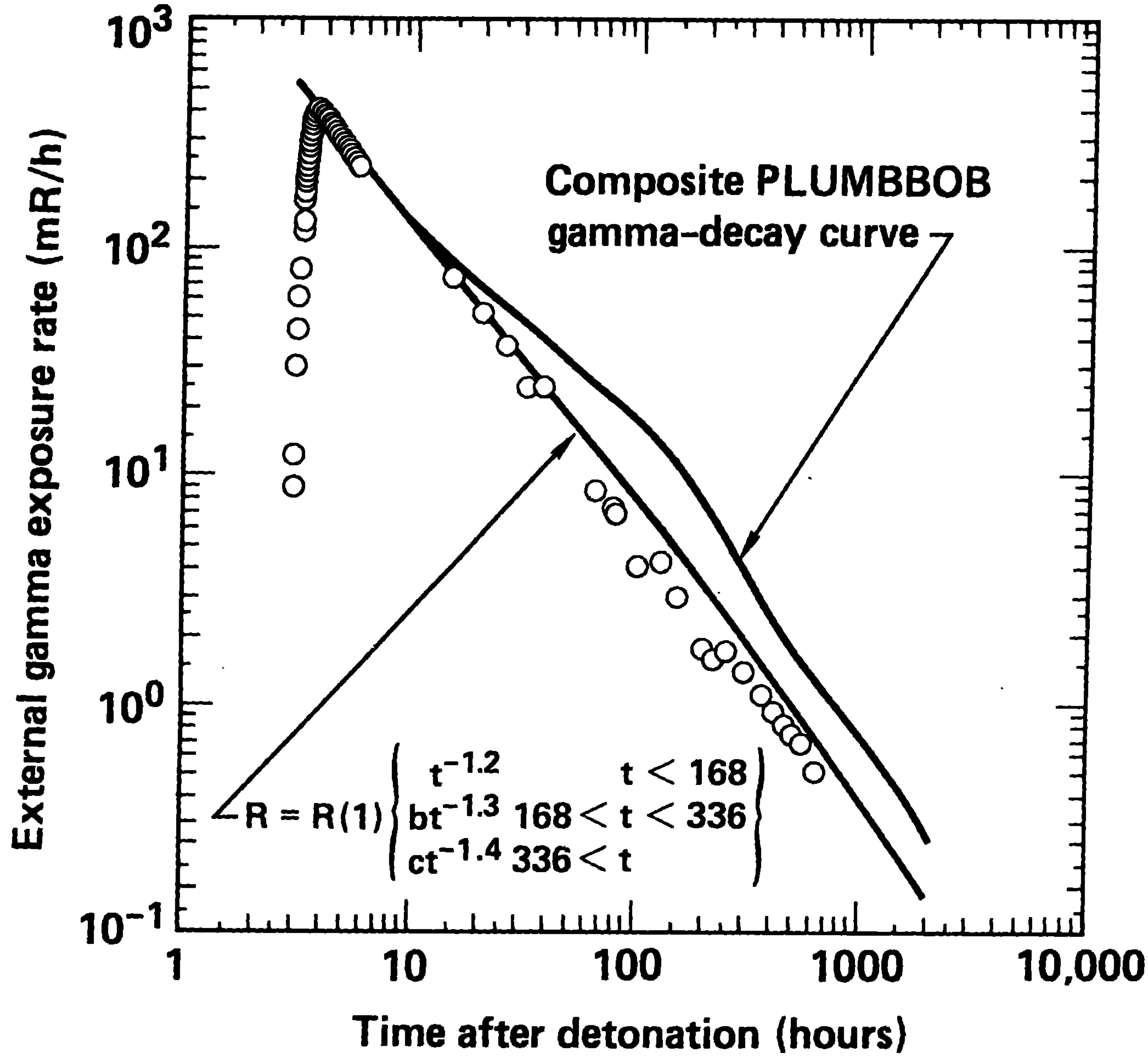
GROSS GAMMA EXPOSURE RATE (mR/HOUR)
TIME (H+HOUR)
$t^{-1.26}$ DECAY RATE

Figure 2.



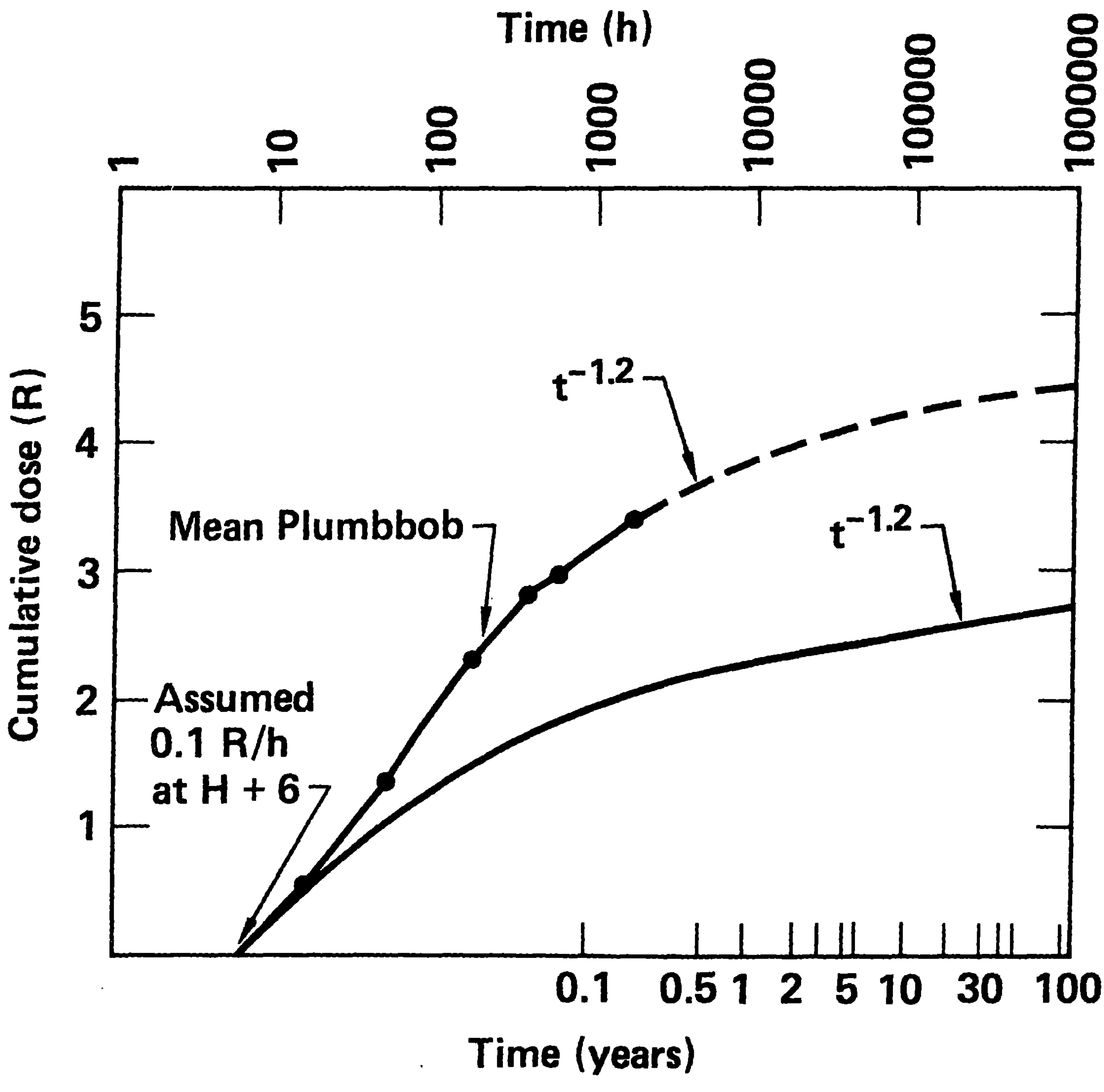
1Ø^3
1Ø^2
1Ø^1
1Ø^0
1Ø^-1
GROSS GAMMA EXPOSURE RATE (mR/HOUR)
t^-1.26 DECAY RATE
1Ø^0
1Ø^1
1Ø^2
1Ø^3
TIME (H+HOURS)

Figure 3.



10^3
10^2
10^1
10^0
10^{-1}
External gamma exposure rate (mR/h)
1
10
100
1000
10,000
Time after detonation (hours)
Composite PLUMBBOB gamma-decay curve
$R = R(1)\begin{cases} t^{-1.2} & t < 168 \\ bt^{-1.3} & 168 < t < 336 \\ ct^{-1.4} & 336 < t \end{cases}$

Figure 4.



Time (h)
1
10
100
1000
10000
100000
1000000
5
4
3
2
1
Cumulative dose (R)
$t^{-1.2}$
Mean Plumbbob
$t^{-1.2}$
Assumed
0.1 R/h
at H + 6
0.1
0.5
1
2
5
10
30
100
Time (years)

Figure 5.